VERMONT METHANE PILOT PROJECT

RESOURCE ASSESSMENT

Prepared for:

Vermont Department of Public Service

and the

Vermont Department of Agriculture, Food and Markets
Montpelier, Vermont

Prepared by:

Jeffrey E. Fehrs, P.E.
Williston, Vermont

July 2000

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY

This Resource Assessment was completed as part of the Vermont Department of Public Service (DPS) and the Vermont Department of Agriculture, Food and Markets (AGR) project to explore the technical feasibility, demonstrate the potential of, and promote anaerobic digestion and methane recovery and use on Vermont farms. The DPS and AGR recognize the ability of anaerobic digestion systems could play in helping farmers achieve manure management goals, decreasing their energy requirements, and providing a source of additional income. Other benefits of farm-based anaerobic digestion include diversifying Vermont's energy mix, creating new sources of renewable energy, and decreasing emissions of greenhouse gases.

The purpose of the resource assessment is to quantify on a statewide basis the amount of dairy manure and other organic residues and wastes that are generated and the amount could potentially be used in farm-based anaerobic digestions systems. Estimates of the electrical energy potential of farm-based anaerobic digestion are made based on quantities potentially available and assumed conversion factors and efficiencies. The residues and wastes included in the assessment are dairy manure; other manures (i.e. beef cow, pig, horse, poultry, goats, sheep); cheese whey; food processing residuals; brewery residuals; food waste; and biosolids (also referred to as sewage sludge).

Although biosolids were considered, they were ultimately rejected due to concerns over regulations, characteristics, and public perception.

Presented in Table A is a summary of the organic residues and wastes generated, potentially available, and electrical energy potential of the organic residues and wastes in Vermont. Overall, over 5.1 million wet tons per year of organic residues and waste are generated in Vermont. Of this amount, over 3.4 million wet tons per year, or about 2/3 of that generated is potentially available for farm-based anaerobic digestion. Although the amount of organic residues and wastes potentially available appears large, the electrical energy potential is just under 30,000 kW (or 30 MW), which is surprisingly small. Assuming there are 1,693 active dairy farms in the state (based on AGR inspection reports for July 1999), the overall average energy potential per dairy farm is calculated to be just under 18 kW.

From an energy potential standpoint, dairy manure represents the vast majority of the resource available in Vermont. About 94% of the estimated 30,000 kW potential is from dairy manure. Cheese whey, at about 3% of the total resource, is the next largest resource, followed by other manures (2% of the total resource) and food waste (1% of the total resource). Brewery residuals and food processing residuals are best described as having minimal energy potential.

The results of the resource assessment strongly suggest the DPS and AGR project focus primarily on dairy manure as the "feedstock" for farm-based anaerobic digestion systems. However, this should in no way discount the role the other residuals and wastes could play in individual systems. Many of the other residuals and waste generated in Vermont need better management or disposal options. An appropriately located farm-based anaerobic digestion system could receive significant quantities of the other residues and wastes. Staff at two companies, one that generates brewery wastewater and one that generates food processing residuals indicated that if farm-based systems were available now, they would seriously consider using them. Cost is a factor that would ultimately drive their decision to use or not use farm-based systems. But it appears that if farms charged low or no tipping fees to accept the material, the companies would deliver their residuals to the farm. Several solid waste districts in the state are seriously considering implementing or expanding food waste collection and beneficial use programs. Again, cost will be a driving factor, but if farms accept the material for a low to no tipping fee, it is reasonable to assume that the districts or private haulers would utilize farm-based systems for all or a portion of the food waste collected.

This study is a macro- or statewide resources assessment that estimates resources generated and potentially available throughout the entire state. While this information is very important to understanding the potential of farm-based anaerobic digestion systems in Vermont, it is of limited use to understanding what organic residuals and wastes would be available to a specific farm-based system. The DPS and AGR project is conducting economic feasibility studies of specific farms to understand if and how anaerobic digestion systems would benefit Vermont farms. One task that could assist the economic feasibility study is a micro-resource assessment to learn what organic residuals and waste would be available, and at what price (positive, zero, or negative). The availability of other residuals and wastes could have a significant impact on the economics of a farm-based system.

TABLE A: Organic Residuals and Wastes Generated, Potentially Available, and Energy Potential in Vermont

ORGANIC RESIDUE OR WASTE	AMOUNT GENERATED (tons/year)[(a)]	POTENTIALLY AVAILABLE (tons/year)[(a)]	ENERGY POTENTIAL ($kW_{electric}$)
DAIRY MANURE	4,053,600	3,121,300	**28,000 kW**
OTHER MANURES			
Beef Cows	276,000	27,600	230 kW
Hogs and Pigs	6,000	3,000	20 kW
Horses and Ponies	241,000	24,100	380 kW
Poultry	8,000	5,400	90 kW
Goats	3,000	300	10 kW
Sheep and Lambs	18,000	1,800	30 kW
			Subtotal = 760 kW
CHEESE WHEY	459,000	184,000	**990 kW**
FOOD PROCESSING RESIDUALS			
Wastewater	310,000 gal/yr	310,000 gal/yr	1.5
Lagoon Sludge	100,000 to 400,000 gal/yr	100,000 to 400,000 gal/yr	0.5 to 2.1
Production Line Rejects	120 to 180	120 to 180	1.7 to 2.5
			Subtotal = 3.7 to 6.1 kW
BREWERY RESIDUALS			
Spent Grains	2,000	0	0
Spent Yeast	133	0	0
Wastewater	9,300,000 to 18,600,000 gal/year	1,300,000 gal/yr	5
			Subtotal = 5 kW
FOOD WASTE	48,000	12,000	**220 kW**
		TOTAL	**29,760 kW**

(a): Except where noted.

INTRODUCTION

Vermont is well known for its picturesque dairy farms, and the state draws tremendous economic, open space, and other benefits from its working farms. It is also well known that farming in Vermont is under increasing economic, regulatory, energy, land use, and other pressures. Each year the number of active farms in the state decreases, and once gone chances are an inactive farm will not return to active farming.

Manure management is one of the larger issues facing dairy and other farms in Vermont, as well as the agriculture and livestock industry in the U.S. The traditional techniques used to manage manure on farms are coming under increasing scrutiny There is growing interest in anaerobic digestion as a technology that can reduce pollutants, odors, and methane emissions resulting from traditional manure management techniques. The U.S. Environmental Protection Agency and the U.S. Department of Agriculture's Natural Resources Conservation Service have created the AgSTAR Program, which is a voluntary program designed to encourage the use of livestock manure as an energy resources, primarily if not solely through anaerobic digestion. Today, an estimated 28 farm-based anaerobic digester are operating in the U.S. and another 10 are planned.

If anaerobic digestion is used on dairy or other farms in Vermont, it will be primarily used as a manure management tool. However, a potentially large amount of organic residuals or wastes are generated in Vermont, and these materials could potential also be collected, transported, processed (if necessary) and used along with manure in farm-based anaerobic digestion systems. The use of these residuals and wastes would increase biogas production, increase electrical and/or thermal energy generation, and possibly increase revenue in the form of tipping fees charged (to accept other organic residues and wastes) and the sale of electrical energy

The Vermont Department of Public Service (DPS) and the Vermont Department of Agriculture, Food and Markets (AGR), with the assistance of a federal grant have undertaken a project to explore the technical feasibility, demonstrate the potential of, and promote anaerobic digestion and methane recovery and use on Vermont farms. In undertaking this project, the DPS and AGR recognize the ability of anaerobic digestion systems could play in helping farmers achieve manure management goals, decreasing their energy requirements, and providing a source of additional income. Other benefits of farm-based anaerobic digestion include diversifying Vermont's energy mix, creating new sources of renewable energy, and decreasing emissions of greenhouse gases. Specific goals of the project include:

- Research methods to reduce the cost of and increase the efficiency of anaerobic digestion, methane recovery, and methane utilization as fuel;
- Develop partnerships with various private- and public-sector agencies, companies, and experts involved in farm-based anaerobic digestion and methane utilization;
- Assess the economic benefits and liabilities of farm-based anaerobic digestion and methane utilization
- Establish sites to demonstrate the viability of the technologies;

- Understand the quantity of and energy potential of organic residuals and wastes that could be utilized in farm-based anaerobic digestion systems;
- Identify opportunities for centralized or cooperative anaerobic digestion systems serving a number of farms; and
- Promote the concept of farm-based anaerobic digestion.

PURPOSE OF THE RESOURCE ASSESSMENT

The purpose of the resource assessment is to quantify on a statewide basis the amount of dairy manure and other organic residues and wastes that are generated and the amount could potentially be used in farm-based anaerobic digestions systems. Estimates of the electrical energy potential of farm-based anaerobic digestion are made based on quantities potentially available and assumed conversion factors and efficiencies.

ORGANIC RESIDUALS AND WASTES INCLUDED

An initial phase of the resource assessment was to identify what organic residuals or wastes are either generated in large quantities or are problematic in terms of their management and/or disposal. The purpose of this initial step was to identify those residuals or wastes that are most likely to be available to farm-based anaerobic digestion systems. "Organic" residuals or wastes were focused on because they typically contain sufficient volatile solids and other characteristics necessary for methane (and energy) production. Those organic residuals and wastes that are generated in large quantities or are problematic in terms of management or disposal were focused on because generators of these materials are likely to be interested in either new markets or management options. Farm-based anaerobic digestion systems may be a cost-effective management option for these materials.

For purposes of this resource assessment, "organic" refers to residuals or waste materials that are readily amiable to anaerobic digestion, fairly homogeneous, and do not contain materials which could affect the ultimate management (assumed to be land application on agricultural land) of the digested effluent. Several residuals or wastes that may be considered "organic" by some were initially evaluated, but were deemed unacceptable due to contamination and/or ultimate management concerns. These materials include non-recyclable paper and wastewater sludge generated during the manufacturing of paper.

Organic residuals and wastes to include in the resource assessment were identified through two steps:

- An Advisory Committee was established as part of the DPS and AGR project. The Advisory Committee represents a broad range of interests and expertise that apply to farm-based anaerobic digestion. DPS and AGR staff and the Advisory Committee provided information on potential organic residuals and wastes to include and reviewed those recommended by the author.

- Interviews were conducted with staff of solid waste districts, environmental groups, industrial and economic development agencies or organizations, solid waste management companies, and others to learn what organic residuals or waste they believed could potentially be available to farm-based anaerobic digestion systems. Some 20 to 25 different interviews were conducted, and the list presented below is a result of these interviews.

Upon review, the Advisory Committee agreed that the residuals and wastes listed below should be included in the resource assessment.

Dairy Manure, which is manure generated by dairy farms or the portion of a farm that is associated with dairy cows and milk production.

Other Manures, which generated by a variety of livestock animals that may be present on dairy farms and/or other farms or livestock housing facilities.

Cheese Whey, which is a liquid by-product generated during the manufacturing of cheese.

Food Processing Residuals, which are the non-sellable, non-marketable products and by-products, and wastewater solids generated by industries during the manufacturing, preparation, and/or packaging of food products. Although similar, food processing residuals are distinctly different from food wastes.

Brewery Residuals, which are the spent grains, yeast, or wastewater generated by breweries.

Food Waste, which is uneaten food and food preparation wastes generated by residential, commercial, and institutional sources such as restaurants and school cafeterias. Food waste also included that generated by and industrial sources such as factory lunchrooms. Although similar, food wastes are distinctly different from food processing residuals.

Biosolids, which are the solids generated by the biological treatment of municipal wastewater at public and private wastewater treatment facilities (WWTFs). Although termed "solids", biosolids may actually be in a liquid or semi-solid state

It is also important to note that while biosolids are included in the resource assessment, the Advisory Committee established as part of the overall project judged biosolids as unavailable to farm-based anaerobic digestion systems primarily due to potential regulatory concerns.

GEOGRAPHIC AREA INCLUDED

The geographic area addressed by the resource assessment is the State of Vermont, and the quantity of organic residues and wastes presented are statewide estimates. It is important to note that organic residues and wastes generated outside the state could be available and used in

Vermont farm-based anaerobic digestion systems. It is beyond the scope of this resource assessment to quantify the potential availability of these organic residues and wastes.

DEFINING GENERATION AND POTENTIALLY AVAILABLE

The research completed as part of the resource assessment attempts to answer two different questions: what amount of manure and other organic residues and wastes is generated in Vermont, and what amount is potentially available to farm-based anaerobic digestion systems.

Generation refers to the total amount of a material that is produced regardless of the ability to collect or use the material in anaerobic digestions systems, the impact of other beneficial uses or disposal options, or other factors that would divert or cause the material to not be used for anaerobic digestion.

Potentially Available refers to that portion of the amount generated that would likely be collected, processed, and transported to farm-based anaerobic digestion systems, if such systems existed within appropriate transportation distances. The estimates of quantities potentially available attempt to consider the key factors that affect the ability to collect, process, and transport organic residues and wastes. As such, the amount potentially available is a reasonable estimate of the quantity that could be expected to be delivered or available to farm-based anaerobic digestion systems.

It is important to note that the resource assessment investigated organic residues and wastes from a macro- or statewide perspective. No attempt was made to look at these resources from a micro- or site-specific perspective. These two perspectives are very different, and it is usually not possible to relate one to the other. The quantities presented in this statewide or macro-resource assessment should not be used to estimate the quantity that would be potentially available to a specific farm-based anaerobic digestion system. To estimate the quantity (and price or tipping fee) of organic residues and waste available to a specific farm, a site-specific or micro-resource assessment is needed.

ESTIMATES OF ELECTRICAL ENERGY PRODUCTION

Biogas produced from anaerobic digestion of organic residues and wastes contains between 55% and 80% methane, and can be used in a wide variety of electrical energy, thermal energy, or cogeneration systems. For simplicity and for comparison purposes, the biogas produced from organic residues and wastes is assumed to generate electricity only.

Anaerobic digestion is a biological process where organic materials are degraded by several different and districts types of bacteria. Key factors affecting production of biogas are biodegradable content of the organic material(s), digester retention time, and operating temperature. The theoretical or optimum yield is reported to be:

8 - 11 SCF CH_4/lb $VS_{removed}$, or

5.62 SCF CH_4/ lb $COD_{removed}$.

Where:

SCF = standard cubic foot.
CH_4 = methane.
$Vs_{removed}$ = volatile solids removed during anaerobic digestion.
$COD_{removed}$ = chemical oxygen demand removed during anaerobic digestion.

When possible, methane production is estimated based on volatile solids content. However, for two residuals (a food processing residual and a brewery residual) information on the volatile solids content was not available, and methane production was based on COD removal. In the case of food waste, good information on volatile solids content and COD was not readily available, and methane production was based on the reported performance (biogas production per weight of food waste) of an operating food waste anaerobic digester

The amount of volatile solids removed by operating animal manure anaerobic digestion systems is reported in **The Casebook of Biogas Utilization** to range from 26% to 63%. The estimates of biogas production in this study assume a volatile solids reduction of 50%. The reduction in COD for industrial anaerobic digestions systems is reported in **The Casebook of Biogas Utilization** to range from 56% to 97%. However, the COD reduction for similar food processing residuals ranged from 92% to 97%, and for simplicity sake a COD reduction of 100% is assumed. For brewery residuals, a COD reduction of 75% is reported.

Once methane production was estimated, the quantity of electrical energy produced was based on the following assumptions:

Energy content of methane is assumed to be 912 Btu/SCF.

Electric generation heat rate will vary significantly depending on the technology or equipment using biogas. The heat rate of internal combustion engine driving generators is reported to be around 11,000 Btu/kW-hr, while the heat rate of fuel cells is around 9,500 Btu/kW-hr. For purposes of this study, an overall heat rate of 10,000 Btu/kW-hr is assumed.

Capacity factor/yearly equipment operating time will likely vary significantly. For purposes of this study, the yearly equipment operating time is assumed to be 8,760 hours, or a capacity factor of 100% (i.e. the equipment operates 100% of the time). While this assumption will likely never happen, it does accurately estimate the electrical generating capacity of farm-based anaerobic digestion systems. This is because these systems are assumed to have limited, if any biogas storage capacity. As biogas is produced it must be used. If farm-based systems have significant storage capacity, biogas could be stored for use by larger (i.e. capable of producing more electricity) electrical generating equipment, but the equipment could not operate all the time (since stored biogas would be deleted as biogas production could not keep up with use). The 8,760 hour or 100% capacity factor assumption also results is a conservative estimate of electric generating capacity.

Sample Calculation:

Dairy manure potentially available: 3,121,000 tons/year
Solids content: 12.5%
Volatile solids content: 85%
Volatile solids reduction assumed: 50%
Methane production assumed: 8 SCF CH_4/lb $VS_{removed}$

Biogas production:

(3, 121,000 tons/yr)(2,000 wet lb solids/wet ton)(0.125 dry lb solids/wet lb solids)
(0.85 lb VS/lbdry solids)(0.5 lb $VS_{removed}$/lb VS)(8 SCF CH_4/lb $VS_{removed}$)

= 2,652,850,000 SCF CH4/year

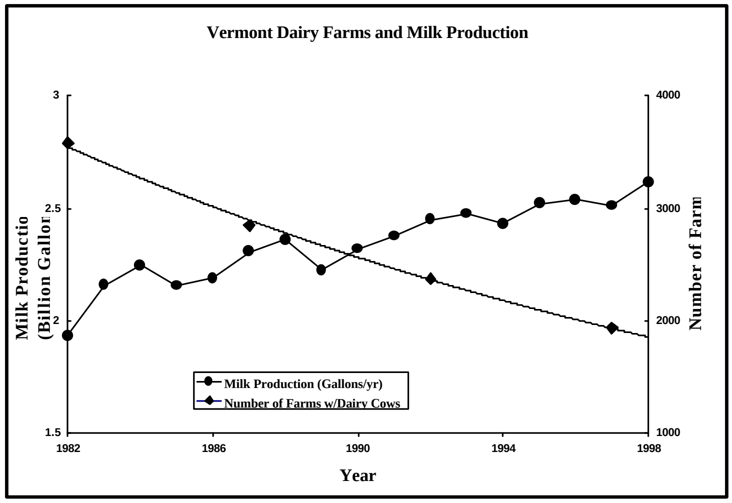
Electrical energy production:

(2,652,850,000 SCF CH_4/yr)(912 Btu/SCF CH_4)(kW-hr/10,000 Btu)(yr/8,760 hr)

28,000 kW

DAIRY MANURE

Vermont is known for its picturesque dairy farms and dairy farming continues to be an important part of the state's economy. Despite their importance, the number of dairy farms in the state has been steadily decreasing. According to the USDA National Agricultural Statistics Service Census of Agriculture, the number of farms with milk cows in 1964 was 6,994. By 1982 the number had decreased to 3,585,and by 1997 only 1,940 remained. However, milk production in the state has steadily increased. According to the Vermont Department of Agriculture, Food & Markets (AGR), about 1.9 billion gallons of milk were produced in the state in 1982, and by 1998 production had increased to about 2.6 billion gallons. Overall, between 1982 and 1998, milk production increased by about 37% while the number of dairy farms decreased by about 46%.



Dairy manure typically refers to the mixture of excreted cow manure and other materials that must be removed from barns on dairy farms and managed in some manner, typically by land application. The material consists of primarily milking cow manure, but may also contain other non-lactating cow manure, bedding materials, and waste materials generated in milkhouses or parlors. Depending on how dairy manure is collected, the material may also contains significant amount of wash water and/or precipitation.

According to AGR, there were about 1,700 dairy farms in the state as of July 1999, and the average dairy farm has about 90 milking cows. This indicates the overall milking cow population in the state is just over 150,000.

Many factors affect dairy manure production, and dairy manure production is not a function of milking cow population only. The factors that affect production include:

- Animal weight;
- Type and quantity of feed;
- Type of confinement and manure management;
- Time spent in confinement;
- Other non-dairy cow manures collected along with milking cow manure; and
- Foreign materials commingled with dairy manure, including bedding materials, wasted feed and water, flush water, and soil.

It appears that manure production from milking cows is closely related to milk production, and that production can be estimated based on 3.1 wet pounds of manure per gallon of milk produced. This equation is used in the **Dairy Manure Production Estimator** to estimate the amount of manure produced by milking cows. Other equations are used to estimate manure production from non-milking cows and other materials commingled with manure. The **Estimator** was developed at the Plant and Soil Science at the University of Vermont as a tool to help dairy farmers and others estimate manure production for land application, storage, and other management.

DAIRY MANURE GENERATION

The Vt. Dept. of Agriculture maintains records of milk production in the state. The records are based on reports filed by handlers who haul raw milk from dairy farms to dairies or other end users. Overall, a reported 2,615,223,469 pounds of raw milk was hauled in 1998. This quantity is believed to accurately estimate total milk production on dairy farms. Some of the raw milk produced is never hauled from farms due to contamination, spills, on-farm use, local sales of raw milk, or other reasons. However, this amount is believed to be small compared to that hauled.

Applying the 3.1 pounds of manure per pound of milk produced, a calculated 4,053,600 tons of manure was excreted by milking cows in 1998. It is important to note this quantity is excreted manure production and does not include other materials typically found in dairy manure, including other non-lactating cow manure, bedding materials, and milkhouse wastes. The quantity and characteristics of the other materials is variable, and it is beyond the scope of this project to estimate quantities and potential methane production. Because the other materials are not included in estimates of excreted manure, this estimate will underestimate (or conservatively estimate) the quantity actually generated.

ESTIMATES OF DAIRY MANURE POTENTIALLY AVAILABLE

Because milk cows typically spend some time outside and may not always be confined to barns or hard surfaces where manure can be collected, a portion of the manure excreted cannot be collected, and is not available for anaerobic digestion. Overall, the amount of time milking cows spend in barns or on hard surfaces is relatively high Information presented in **Anaerobic Digesters for Dairy Farms** published by the Department of Agricultural and Biological Engineering at Cornell University indicates milk cows are confined in barns or on hard surfaces about 88% of the time. Results of a survey of 97 dairy farms included in **Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York** published by the Department of Agricultural and Biological Engineering at Cornell University indicate that mature cows spend about 12% of the time outside, or about 88% of the time in barns. The example provided as part of the **Estimator** states milk confinement is 282 day equivalents, or about 77% of the time. It is likely the actual amount of confinement varies greatly from farm to farm. For purposes of this analysis, it is conservatively assumed that 77% of manure excreted by milking cows can be collected and is potentially available. Applying the 77% factor to the total amount of manure excreted by milk cows, an estimated 3,121,300 tons/year are potentially available

ENERGY PRODUCTION FROM DAIRY MANURE

In order to estimate the energy production from dairy manure, an assumption is made that methane is generated by excreted milking cow manure. As noted above, dairy manure typically contains various materials in addition to the manure from milking cows. Dairy manure may also contain other (non-lactating) cow manure, bedding materials, and milkhouse wastes. Both other cow manure and milkhouse wastes likely contain volatile solids that would produce methane in anaerobic digesters, and not accounting for these materials underestimates the actual energy production. Bedding materials, including sawdust or chips, straw, and sand will likely contain limited, if any volatile solids that would be converted to methane in anaerobic digesters. Not including bedding materials in estimates of energy potential will likely have a minimal impact on the estimate.

Assuming 3,121,300 tons/year of dairy manure is potentially available, assuming the characteristics listed at right, and using the methodology discussed in the Introduction, the energy potential of methane generated by anaerobic digestion of dairy manure is estimated to be slightly more than 28,000 kW.

DAIRY MANURE CHARACTERISTICS	
Solids Content	12.50%
Total Solids	10.00 lb/d/1000#
Volatile Solids	8.50 lb/d/1000#
Volatile Solids:Total Solids Ratio	85%
Source: Agric. Waste Mgmt. Field Handbook	

OTHER MANURES

In addition to dairy cows, Vermont's agricultural industry includes a variety of other livestock animals. These animals include beef cows, hogs and pigs, horses and ponies, poultry, goats, and sheep. The purpose of this section is to quantify the amo unt of manure produced by these animals.

Manure typically refers to the mixture of excreted manure and other materials that must be removed from barns or other hard surfaces and managed in some manner. The material consists of primarily manure, but may also contain organic materials such as bedding. Depending on how the manure is collected, the material may also contain significant amount of wash water and/or precipitation.

OTHER MANURE GENERATION

Estimates of other manure production are based on esti mates of animal populations, typical animal weights, and manure generation factors. Animal populations were obtained from the 1997 USDA Census of Agriculture livestock inventories. The Census of Agriculture inventories are believed to be somewhat inaccurate, but in most cases is the only data available. The exception is horse population, where good information was obtained from Josie Davis of the Department of Animal Science at the University of Vermont. Typical animal weights were estimated based on information from either the Vermont Department of Agriculture, Food and Markets, individuals knowledgeable about livestock in Vermont, or national organizations. The as excreted manure generation data is from **Chapter 4 Agricultural Waste Characteristics** of the USDA Soil Conservation Service's Agricultural Waste Management Field Handbook. Estimates of other manure generation are presented in Table 1 along with the data used to obtain the estimates.

ESTIMATES OF OTHER MANURES POTENTIALLY AVAILABLE

Because livestock animals typically spend some time outside and may not always be confined to barns or hard surfaces where manure can be collected, a portion of the manure excreted cannot be collected, and is not available for anaerobic digestion. Presented in Table 2 are estimates of the portion of time livestock is confined to barns or hard surfaces as well as estimates of manure potentially available.

ENERGY PRODUCTION FROM DAIRY MANURE

In order to estimate the energy production from other livestock manures, an assumption is made that methane is generated only from the excreted manure. As noted above, livestock manure typically contains various materials such as bedding materials and dirt. Bedding materials, including sawdust or chips, straw, and sand will likely contain limited, if any volatile solids that would be converted to methane in anaerobic digesters. The same is true for dirt. Not including bedding materials in estimates of energy potential will likely have a minimal impact on the estimate of energy production.

Presented in Table 3 is the estimated energy potential from other animal manures as well as the manure characteristics used in the estimates. The methodology used to estimate energy potential is the Introduction. Overall, the energy potential of methane generated by anaerobic digestion of other animal manures is estimated to be about 760 kW.

TABLE 1: Other Animal Manure Generation

Animal	**State Population**[a]	**Typical Animal Weight** (pounds)	**Manure Generation Factor**[b] (lbs/day/1000 lbs)	**Manure Generation**[c] (tons/year)
Beef Cows	21,000[k]	1,200[e]	60	276,000
Hogs and Pigs	2,200	200[f]	72.7	6,000
Horses and Ponies	24,000	1,100[g]	50	241,000
Poultry[d]	224,000[d]	3[h]	62.0	8,000
Goats	2,617	150[i]	40.0[l]	3,000
Sheep and Lambs	13,972	180[j]	40.0	18,000

(a): State population of beef cows, hogs, pigs, and poultry are based on data presented in the **1998 New England Agricultural Statistics** published by the New England Agricultural Statistics Service, a field office of the USDA National Agricultural Statistics Service. The state population of horses and ponies is based on estimates provided by Josie Davis, Department of Animal Sciences, University of Vermont. The state population of goats, sheep, and lambs are based in the 1997 USDA NASS Census of Agriculture inventory.

(b): Manure generation factors are from **Chapter 4 Agricultural Waste Characteristics** of the USDA Soil Conservation Service's Agricultural Waste Management Field Handbook. The factors used are for as excreted manure, which does not included materials such as bedding and dirt that may actually be present in livestock manure collect in barns or on solid surfaces.

(c): Manure generation was rounded to the nearest 1,000 tons/year.

(d): Includes layers, pullets, and broilers, does not include pullet chicks.

(e): According to the Vermont Department of Agriculture, Food and Markets' Website **About Cows!** located at http://www.state.vt.us/agric/dairy/cows/.htm, the typical weight of cows ranges from 900 to 1,500 pounds depending on breed. A typical weight of 1,200 pounds is assumed.

(f): According to **PORK FACTS 98/99** published by the National Pork Producers Council, the typical market pig weights 250 pounds. A typical weight of 200 pounds is used to account for pigs that have not reached market weight.

(g): Typical horse weight provided by Josie Davis, Department of Animal Sciences, University of Vermont.

(h): According to a large egg producer located in Vermont, the typically layer weights about 3½ pounds. A weight of 3 pounds is assumed to account for birds that have not reached maturity.

(i): According to the American Dairy Goat Association Website **Dairy Goat Facts** located at http://www.adga.org/facts.htm, the mature (36 months) large breed male goat weighs up to 205 pounds. A weight of 150 pounds is assumed to account for female and goats that have not reached maturity.

(j): Based on information provided on dual purpose breeds in the American Sheep Industry Association, Inc. website **Directory of U.S. Breeds of Sheep** located at http://www.sheepusa.org/resource/shbreeds.htm, the mature body weight of rams can vary between 160 and 350 pound and ewes can vary between 120 and 240 pounds, depending on breed. A typical weight of 180 pounds is assumed.

(k): Includes 13,000 beef cows that calved, 4,000 beef replacement heifers (500 pounds and over), and 4,000 steers (500 pounds and over). This quantity may underestimate the population of beef cows.

(l): Chapter 4 Agricultural Waste Characteristics of the USDA Soil Conservation Service's Agricultural Waste Management Field Handbook does not include information on goat manure. The manure generation factor for sheep and lambs is assumed to apply to goats.

TABLE 2: Estimates of Other Manures Potentially Available.

ANIMAL	**Manure Generation** (tons/year)	**Time Spent In Barns And/Or On Hard Surfaces**[a] (%)	**Amount Potentially Available** (tons/year)	**Comments**
Beef Cows	671,000	10%	67,100	High amount of pasture management
Hogs and Pigs	6,000	50%	3,000	Some outside management
Horses and Ponies	241,000	10%	24,100	High amount of pasture management
Poultry	8,000	80%	5,400[b]	High amount of management in barns or houses
Goats	3,000	10%	300	High amount of pasture management
Sheep and Lambs	18,000	10%	1,800	High amount of pasture management

(a): Information on livestock management provided by Dan Scruton, Agricultural Development Division, Vermont Department of Agriculture, Food and Markets.

(b): The amount potentially available does not include 1,300 tons/year currently composted, amount available = (8,000-1,300) x 0.80   5,400 tons/year.

TABLE 3: Estimated Energy Production from Other Manures.

ANIMAL	**Manure Potentially Available** (tons/year)	**Solids Content**[a] (%)	**Volatile Solids/ Total Solids Ratio**[b]	**Energy Potential**[c][d] (kW)
Beef Cows	27,600	11.6	0.85	230
Hogs and Pigs	3,000	10.0	0.87	20
Horses and Ponies	24,100	22.0	0.85	380
Poultry	5,400	25.0	0.785	90
Goats	300	25.0[e]	0.83[e]	10
Sheep and Lambs	1,800	25.0	0.83	30
			TOTAL	**760**

(a): Solids content data is from **Chapter 4 Agricultural Waste Characteristics** of the USDA Soil Conservation Service's Agricultural Waste Management Field Handbook.

(b): The ratio is derived from data on total solids and volatile solids characteristics on "as excreted" animal manures presented in **Chapter 4 Agricultural Waste Characteristics**.

(c): Energy potential is estimated based on the methodology discussed in the Introduction.

(d): Estimates of energy potential were rounded to the nearest 10 kW.

(e): Chapter 4 Agricultural Waste Characteristics of the USDA Soil Conservation Service's Agricultural Waste Management Field Handbook does not include information on goat manure. The manure characteristics for sheep and lambs are assumed to apply to goat manure.

CHEESE WHEY

Whey is a collective term referring to the watery portion of milk remaining after coagulation or curdling step of cheese manufacturing. The exact composition of whey will differ depending on the type of milk used, cheese being produced, and the specific manufacturing processed used. In general, whey consists of 94% water, and the remaining solids consist primarily of lactose (a simple carbohydrate also referred to as milk sugar), proteins, and minerals. A general rule-of-thumb is that for every 100 pounds of milk, 10 pounds of cheese and 90 pounds of whey are produced.

Whey is categorized into two types: acid whey and sweet whey. Acid whey (pH<5.1) is produced from cottage cheese and other "fresh" cheeses such as cream and ricotta cheese. Sweet whey (pH>5.6) is produced from all other cheeses, or those that use rennet as a coagulation agent. Acid and sweet whey may be condensed or dried, or various materials may be extracted or produced from it. These products are commonly used as used food additives or supplements. Specific high-value proteins with health or medical benefits can be separated from sweet whey, including bovine lactoferrin. Bovine lactoferrin is used as an immune system stimulant, and is used in the treatment of cancer and tumors. Bovine lactoferrin is currently extracted from whey produced by a cheese manufacturer in Vermont.

Whey Products:
Concentrated
Dried
Reduced Lactose Whey
Reduced Mineral Whey
Whey Protein Concentrate
Dairy Products Solids
Lactose
Whey Protein Isolate
Lactalbumin

Source:
Am. Dairy Products Institute

Although whey processing makes economic sense at large cheese production plants, smaller companies do not have the financial or technical resources to invest in the whey processing equipment or technology. These companies typically manage their whey by giving it away as animal feed or by paying to have it land applied. The cost to land apply whey is significant, the cost is reported to range from $20 to $40/ton (depending on distance to disposal location), or from 20¢ to 30¢/pound of cheese produced. Several interviewed as part of this project voiced that their cost to dispose whey likely exceeds their raw milk costs.

CHEESE WHEY GENERATION

Data on whey generated in Vermont is not available, and estimates are made based on cheese production. According to the U.S. Department of Agriculture, National Agriculture Statistical Service (NASS), 11 plants produced about 102 million pounds of cheese were produce in Vermont in 1997. This quantity does not include cottage cheese. NASS data on 1998 cheese production is not available due to regulations or policy pertaining to disclosing information about individual plants. NASS' policy is not to publish state (or regional) data when fewer than three firms have reported or if one firm comprises more than 60% of a state's (or region's) total. Since there are more than three companies that produce cheese in Vermont in 1998, the reason must be due to one company producing more than 60% of the total. The NASS does not include data on cottage cheese produced in Vermont since less than three plants produce this cheese

The Vermont Cheese Council, a non-profit technical assistance and promotion organization for Vermont cheese manufacturers lists 22 companies that produce cheese in Vermont. The companies and their locations are presented at right.

CHEESE PRODUCER	LOCATION
Blythedale Farm	Corinth
Cabot Creamery	Cabot
Crowley Cheese Co.	Healdville
Franklin County Cheese Corp.	Enosberg Falls
Grafton Village Cheese Co.	Grafton Village
Jolina Foods	Richmond
K.C. Kritters	Brattleboro
Kingsey Cheese of Vt.	Hardwick
Lazy Lady Farm	Westfield
Lucille Farm	Swanton
Orb Weaver Farm	New Haven
The Organic Cow	Tunbridge
Plymouth Cheese Corp.	Plymouth
Rivendell Meadows Farm	Irasburg
Seward Family Cheese	East Wallingford
Shelburne Farms	Shelburne
Skunk Hollow Farm	Greensboro
Stella Foods	Hinesburg
Green Mountain Blue Cheese	Highgate Center
Vermont Butter & Cheese Co.	Websterville
Vermont Shepherd/Major Farm	Putney
Willow Hill Farm	Milton
Source: VT. Cheese Council	

Assuming about 102 million pounds of cheese where produced in Vermont in 1997, and assuming each pound of cheese produces 9 pounds of whey, an estimated 918 million pounds, or 459,000 tons of whey were produced in Vermont in 1997.

ESTIMATES OF CHEESE WHEY POTENTIALLY AVAIALBLE

An estimate of cheese whey potentially available is based on cheese production and estimates of how much whey is used in food markets or other high value markets. The remaining whey is managed as an animal feed or is land applied, and is assumed to be potentially available to farm- or co-operative-based anaerobic digestion systems. As noted above, an estimated 459,000 tons of whey were produced in 1997.

Of the 459,000 tons, a significant amount is processed into various food or other high-value products. Based on discussions with various cheese manufacturers as well as interpretation of NASS data, an estimated 60% of the cheese whey generated in Vermont is currently processed. This means the remaining 40%, or about 184,000 tons per year are potentially available

ENERGY PRODUCTION FROM CHEESE WHEY

The solids contained in whey are comprised of about 70% lactose and 12% is proteins, both of which will be broken down and converted to methane and carbon dioxide during anaerobic digestion. Based on the USDA NRCS's Agricultural Waste Management Field Handbook, the volatile solids content of sweet whey is about 6.35% (weight basis), or about 92% of total solids. Using the methodology described in the Introduction, the amount of whey potentially available, and a volatile solids content of 6.35%, the resulting potential energy production is about 990 kW.

FOOD PROCESSING RESIDUALS

Food processing residuals are generated by industries during the manufacturing, preparation, and/or packaging of food products. The industries that generate food processing residuals are classified by the North American Industry Classification System (NAICS) as Part 311 Food Manufacturing. In general, food processing residuals are generated as:

- Off-specification products;
- Spoiled or contaminated products;
- Product overruns;
- Experimentation or developing new products;
- Manufacturing by-products; and
- Solids removed from or resulting from the treatment of wastewater and/or wash water.

Because these residuals are produced by or during the manufacturing of food products, they will likely be organic in nature and may contain volatile solids or other components that could be converted to methane in farm-based anaerobic digesters. Food processing residuals are produced by a wide variety of industries using widely varying feedstocks and utilizing different manufacturing processes, production techniques, or waste management processes. Due to this, food processing residuals will have widely varying characteristics that affect methane and energy production.

Although dairy product manufacturing is classified under the NAICS as Part 311 Food Manufacturing, in this study cheese whey (a by-product of cheese manufacturing) is address separately. Also, it should be noted that food processing residuals are different from waste food. Waste food is prepared and unprepared food discarded by residential, commercial, and institutional sources such as homes, restaurants, cafeterias, and grocery stores. Waste food is also addressed separately.

FOOD PROCESSING RESIDUAL GENERATION

Ideally, data on the generation and management of food processing residuals would be available as part of the solid waste management data and planning by the Vermont Agency of Natural Resources (ANR). If available, this information could be analyzed to estimate the portion available to farm-based anaerobic digesters. Food processing residuals are clearly defined as both solid waste and municipal solid waste (MSW) under Vermont's Solid Waste Management Rules. About 10 years ago, the ANR along with the solid waste districts attempted to determine how much commercial and industrial waste (including food processing residuals) is generated and managed in the districts. Due to differences in how the districts collected data, useful statewide information cannot be deduced from the data. Based on discussions with ANR Solid Waste Section staff as well as a review of the **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revisions** dated January 1999, little if any information is available on food processing residuals through the ANR or from a statewide perspective.

Since statewide data or information was not available, a different approach was needed. The approach used was to attempt to identify those industries in Vermont that either generate large quantities of food processing residuals or are having problems managing the food processing residuals they do generate. Food processing residuals that are either generated in large quantities or are "problematic" in terms of management or disposal could be available to farm-based anaerobic digesters. In order to identify problematic residuals, interviews were conducted with representatives of the 14 solid waste districts in the state, the Vermont Department of Economic Development, the Associated industries of Vermont, and a large solid waste hauler operating in the state. The purpose of the interviews was to obtain information on what food processing residuals generated in the district or state are "problematic" in terms of quantities generated, or management and/or disposal. In addition, companies known to be major food product manufactures in the state were contacted. The purpose of these interviews was to learn what food production residuals the company produces, how the residuals are managed, and if any of the residuals would be potentially available to farm-based anaerobic digesters.

Overall, the interviews indicate there is relatively few "problematic" food processing residuals generated in the state. Most food processing residuals are either recycled (or beneficially used) through composting, land application, or use as animal feed, or are disposed in permitted solid waste disposal facilities. These management options all indicate the generator incurs a cost to dispose their residual, although in some cases the only cost may be transporting the material to the recycling or disposal facility. This indicates that if farmers were to accept food processing residuals and charge no fee, it is quite possible that some, and in some locations significant quantities of food processing residuals could be available. Some solid waste district staff expressed concerns that composting programs established by the districts could be negatively impacted if farmers began accepting food processing residuals and other organic wastes for free. This is because the districts need to charge a tipping fee to operate the compost projects, and farmers accepting the same materials for free could result in significant quantities being diverted from the compost projects.

However, two companies interviewed indicated they generate food processing residuals that could potentially be available to farms with anaerobic digestion systems. Information on the type and quantity of residuals is presented below.

FOOD PROCESSING RESIDUALS POTENTIALLY AVAILABLE

As noted above, two companies known to be relatively large food product manufacturers indicated they would be interested in supplying their residuals to farms with anaerobic digesters. Presented in Table 4 is information on the type, quantity, and characteristics of the three food processing residuals as well as an estimate of the energy potential. As shown in Table 4, the energy potential of the three residuals is relatively small, and is at most 6.1 kW.

TABLE 4: Food Processing Residuals Potentially Available.

Description	Quantity	Assumed Characteristics	Energy Potential (kW)[f]	Comments
Wastewater	310,000 gal/year	10,000 mg/l BOD[a][b]	1.5 [b][c]	Quantity listed is the total wastewater generated at multiple locations
Lagoon Sludge	100,000 to 400,000 gal/year	15,000 mg/l volatile solids[d]	1.0 to 4.2	Generated at one location
Production Line Rejects	10 to 15 tons/month	Combination of solids and liquids[e]	1.7 to 2.5[e]	Generated at one location
Total = 3.7 to 6.1 kW				

(a): BOD concentration is estimated based on data provided by the company.

(b): A simplifying assumption is made that COD concentration equals BOD concentration so that an estimate of energy potential can be made using the methodology discussed in footnote c. In most cases, the COD concentration of food processing wastewater should exceed the BOD concentration, possibly by a factor or 2 or more. Assuming they COD equals BOD will result in an underestimation of energy potential.

(c): Energy potential is estimated based on a theoretical methane yield of 5.61 SCF CH_4/lb $COD_{Removed}$.(**The Handbook of Biogas Utilization**, SERBEP 1996). For purposes of this estimate, 100% COD removal during anaerobic digestion is assumed. This assumption will slightly over-estimate the energy potential since not all COD would be removed during digesting. However, COD removal is expected to be quite high, likely 95% or greater (**The Handbook of Biogas Utilization**, SERBEP 1996).

(d): Volatile solids concentration was provided by the company

(e): Assumed to have a solids content of 20% and a volatile solids content of 85%.

(f): Calculation of the energy potential is discussed in the Introduction.

BREWERY RESIDUALS

Brewery residuals are the spent grains, yeast, and liquid wastestreams produced by breweries located in Vermont. According to the Vermont Department of Liquor Control (DLC), as of May 1999 there were 26 companies licensed to manufacture alcoholic beverages in the state. The DLC information does not include the specific beverages manufactured, but it appears only beers, wines, and hard ciders are produced in Vermont. Based on the DLC information as well as Vt. Department of Tourism and Markets (DTM) information on breweries of Vermont, it appears at least 16 (of the 26) companies manufacture beer, either for distribution or consumption on-site. Vermont breweries are commonly referred to as "microbreweries" or "brewpubs". Microbreweries produce relatively small batches with emphasis on using quality ingredients and brewing techniques to produce distinctive types of beers. Despite the opinion that Vermont's breweries are micro-breweries, the Institute for Brewing Studies would actually classify four breweries in the state as "regional breweries" (and not microbreweries) since they produced more that 15,000 barrels per year. These breweries are Catamount Brewing, Long Trail Brewing, Otter Creek Brewing, and Magic Hat Brewing. Brewpubs are similar to microbreweries, but the beer is produced primarily if not solely for consumption on site. Because brewpubs focus on on-site consumption, the volume of beer produced is typically less than microbreweries.

Vermont Breweries and Brew-Pubs[(a)]

Madison Brewing Co.	Bennington
McNeill's Brewery	Brattleboro
Windbrew Corp.	Brattleboro
Long Trail Brewing Co.	Bridgewater
Trout River Brewing Co.	East Burke
The Three Needs	Burlington
Vt. Pub & Brewery	Burlington
Rock Art Brewery	Johnson
Otter Creek Brewing, Inc.	Middlebury
Koss Brewing Company of Vt.	Morrisville
The Norwich Inn	Norwich
Jigger Hill Brewery, Ltd	So. Royalton
Magic Hat Brewing Co.	So. Burlington
Shed, Inc.	Stowe
Maple Leaf Malt & Brewing, Inc.	Wilmington
Catamount Brewing Co.	Windsor

Source: Vt. Dept. of Liquor Control
(a): May not include all breweries or brew-pubs.

Beer is produced by cooking various grains, hops, flavorings, and other additives into a sweet liquid called "wort" and fermenting the wort into beer. Cooking the grains converts starches to sugars, some of which are converted into alcohol during fermentation. The grains, hops, and other additives are strained from the wort prior to fermentation, and the strained material (commonly referred to as "spent brewers grains") is discarded. The fermentation process produces excess yeast, the majority of which is also discarded. Breweries can also generate significant amounts of wastewater consisting of waste wort or beer along with the wastewater generated by washing and rinsing of equipment, facilities, and beer containers (bottles, barrels, etc).

Based on data presented in the study **Lignocellulosic Feedstock Resource Assessment**, over 1,000,000 dry tons of spent brewers grains were generated in the U.S. in 1996. This amount includes spent grains generated by "large" breweries (over 500,000 barrel/year production capacity), "regional" breweries (between 15,000 and 500,000 barrel/year capacity) as well as microbreweries and brewpubs. Assuming the overall moisture content of the spent grains is

50%, the actual amount of spent grains generated in the U.S. is over 2,000,000 tons. It is interesting to note that in 1996, microbreweries and brewpubs together generated only 0.4% of the total amount of spent grains generated while large breweries generated 97.0%.

The majority of spent grains generated in the U.S. are used as animal feed. Spent grains are recognized as being an established feed commodity with high market value. The price of spent grains sold as animal feed is reported to range from $117 to $150 per dry ton ($58.50 to $75.00 per ton assuming a moisture content of 50%).

U.S Brewery Capacity and Spent Grains Generation

Brewery Type	**Capacity** (barrels)[a]	**Spent Grains Generated** (dry tons/yr)	**% of Total**
Brewpubs	357,431	1,162	0.1
Microbreweries	764,768	2,486	0.3
Regional	7,325,300	23,234	2.5
Large	276,150,000	886,238	97.0
Totals	**284,597,499**	**913,120**[b]	**100**[c]

Source: Lignocellulosic Feedstock Resource Assessment
(a): A barrel is equivalent to 31 gallons.
(b): Data has not been adjusted for non-reported data. The actual amount is estimated to exceed 1,000,000 dry tons/yr.
(c): Does not sum to 100% due to rounding.

BREWERY RESIDUALS GENERATION

The study **Lignocellulosic Feedstock Resource Assessment** includes estimates of spent brewery grains on the state level for 1996. The amount estimated to be generated in Vermont is 300 dry tons, or 600 tons assuming a moisture content of 50%. The estimate is based on total brewery capacity in the state and a spent grains generation factor of 0.003 dry tons/barrel (or 3 dry tons per 1,000 barrels). This implies the state brewery capacity was about 100,000 barrels per year in 1996.

It appears this estimate from the study **Lignocellulosic Feedstock Resource Assessment** likely underestimates the amount of spent grains actually generated in the state. Based on research conducted as part of this study, it is likely that 2,000 wet tons of spent grains were generated in 1999. This amount is includes spent grains generated by the four large breweries and does not include that generated by the smaller breweries and brewpubs. Because the smaller breweries and brewpubs are not included, the amount underestimates the actual amount of spent grains generated in the state.

Data on spent grains generation and beer production provided by two of the large breweries indicate the two breweries generate about 20 wet tons of spent grains per 1,000 barrels produced. The four breweries are believed to have produced a total of about 100,000 barrels in 1999, based on actual production figures provided by two breweries and published production capacities for the other two breweries. Applying total production to the spent grains generation factor of 20 wet tons/1,000 barrels, the calculated spent grains generation for the four large breweries is 2,000 tons in 1999.

Information on spent yeast or brewery wastewater generated in the state is not readily available. However, interviews with staff at the four large breweries in the state generated useful information on these two residuals. The focus of the interviews was on the four large breweries since they generate the vast majority of brewery residuals generated in the state. Complete information on the two residuals was not obtained since some breweries do not know or keep tract of yeast and wastewater generation.

Staff at one of the large breweries reported that the residuals generate by the brewery on a bi-weekly basis are approximately:

Brewery Residual	Pounds	Form	% of Total
Spent grains	30,000	Wet solids	92.3%
Yeast	2,000	Liquid	6.1%
Trub[(a)]	500	Liquid	1.5%
Total:	32,500		

(a) A mixture of complex carbohydrates and proteins

The ratio of spent grains to spent yeast generated is 15:1 on a weight bases. Assuming the four large breweries generate spent yeast on a similar weight basis, the total yeast generated by the four breweries is calculated to be about 133 tons in 1998.

Staff at one brewery reported that a typical brewery with a bottling plant generates wastewater at a ratio of 6 gallons wastewater to gallon of beer produced, and that wastewater generation at an efficient brewery/bottling plant may be as low as 3 to 4 gallons per gallon. Since the capacity of the four breweries is 100,000 barrels/year, the combined wastewater generated by the breweries is calculated to be between 9.3 million and 18.6 million gallons/year, or between 25,500 and 51,000 gallons/day. The Biological Oxygen Demand (BOD) concentration of brewery wastewater is known to be relatively high, and is reported to range from about 1,000 mg/l to 8,000 mg/l.

ESTIMATES OF BREWERY RESIDUALS POTENTIALLY AVAILABLE.

The interviews with staff of the four large breweries indicate that overall spent grains and yeast will not be available for anaerobic digestion. This is because the breweries either sell or give away their spent grains as animal feed. One brewery charges farmers $10/container (the container size is unknown, but can be picked up and moved by a forklift) for spent grains while the other three do not charge for it. Giving spent grains away does not necessarily imply it is "free" to the farmer. The farmer who collects the spent grains, yeast, and trub generated at one brewery invested in specialized roll-off containers and vehicles to collect and transport the material. In the other two cases, the farmers are responsible for transporting the material.

Staff at one brewery voiced concern over animal feed markets as a long-term management option. The concern is that as the brewery expands and generation of quantity of spent grains increases, the demand for the material will not keep pace and other markets or disposal option will be needed.

Spent yeast is similar to spent grains. Spent yeast is either mixed with spent grains or managed separately. One staff indicated their spent yeast is valued as a high nutrient animal feed and high nitrogen fertilizer. This brewery dewaters the yeast to make the materials more stable and easier to handle. Another brewery gives it's yeast to farmers who either directly land apply the material or add it to their manure pits. The other two give spent yeast away as animal feed.

It appears that wastewater is different than spent grains or yeast. Two of the breweries are connected to municipal sewers and wastewater treatment facilities, and staff at these breweries did not expressed concerns about how their wastewater was managed. One brewery is located where there are no municipal sewers and all wastewater generated (including the domestic or sanitary wastewater containing human wastes) must be treated prior to disposal in leach fields. The brewery has constructed a wastewater treatment system that includes sludge digestion. The digested sludge is currently hauled to farm manure pits for land application (along with manure). The owner of the brewery was interviewed, and did not express concerns about the treatment system or treated effluent disposal, but is interested in farm-based anaerobic digestion of the sludge. An issue with this sludge is if digestion will be required (to reduce human pathogens) prior to being transported to a farm-based digester. If the sludge is digested, then there will likely be little or no benefit of adding it to farm-based digesters from a methane or energy production perspective. This is because the volatile solids content of the sludge will be reduced (by the on-site digestion system), thereby reducing methane production in a farm-based system. The volume of sludge generated by this brewery is not known.

One brewery is experiencing significant issues with wastewater disposal. This brewery is connected to the municipal sewer system and wastewater treatment plant. The municipality has placed limits on BOD quantities the brewery can discharge to the sewer, which requires the brewery to store and transport a significant portion of its wastewater to another municipal wastewater treatment plant. The brewery is incurring significant cost not only to store and transport the wastewater, but also must pay a tipping fee at the other wastewater treatment plant. The owners of the brewery are investigating anaerobic digesters to reduce BOD loads to below that specified by the municipality. However, staff at the brewery indicate that if farm-based anaerobic digesters were available to accept wastewater on a reliable and long-term basis, they would be given serious consideration as an alternative to an on-site pretreatment system. Currently the total amount of wastewater generated is about 7,000 gallons/day, but could expand to as much as 20,000 gallons/day due to expansion of the brewery's production capacity. The specific quantity of wastewater that must be transported to another treatment plant is not known.

ENERGY PRODUCTION

Breweries generate three residuals that could be potentially be used in farm-based anaerobic digestions systems. These are spent grains, spent yeast, and wastewater. Little, if any of the spent grains and yeast are believed to be available since these materials have value as animal feed. It does appear that some of the wastewater from one brewery is potentially available, but may not be in the future if the brewery owners install an anaerobic pretreatment system. The quantity of wastewater potentially available is not known. An "educated guess" is that the amount is about half of that generated, or about 3,500 gallons/day, or about 1.3 million gallons per year assuming the brewery operates 365 days per year. The BOD is reported to range from 6,000 to 8,000 mg/l. The ratio of Chemical Oxygen Demand (COD) to BOD is assumed to be 1.67 to 1, which is based on the reported COD and BOD levels of a microbrewery in Northern California.

Energy potential is estimated based on a theoretical methane yield of 5.61 SCF CH_4/lb $COD_{Removed}$ for anaerobic digestion systems (**The Handbook of Biogas Utilization**, SERBEP 1996). The COD removal is assumed to be 75%, which is the average value for reported in **The Handbook of Biogas Utilization** for two breweries using anaerobic digestion to treat their wastewater. The methane energy value and electricity heat rate are as described in the Introduction. The calculated energy potential of the wastewater is about 5 kW.

FOOD WASTE

The definition of food waste used in this study is the same as that defined in **Characterization of Municipal Solid Waste in the United States; 1997 Update** published by the U.S. EPA. Food waste is defined as consisting of:

> *"uneaten food and food preparation wastes from residences, commercial establishments (restaurants, fast food establishments), institutional sources such as school cafeterias, and industrial sources such as factory lunchrooms. Food waste generated during the preparation and packaging of food products is considered industrial waste and therefore not included in MSW food waste "*

Similar to the U.S. EPA definition, the definition of food waste used in this study does not include food processing residuals. These residuals, which are a possible resource for farm-based anaerobic digestion systems are addressed in a separate section of this report.

Based on data provided in **Characterization of Municipal Solid Waste in the United States; 1997 Update**, just under 21 million tons of food waste was generated in the U.S. in 1996, or 10.4% of the 210 million tons of municipal solid waste (MSW) that were generated. Because food waste is readily compostable, the material is targeted for diversion from disposal in landfills. According to the **BioCycle Journal of Composting & Recycling** article "Food Residual Composting in the U.S.", there are an estimated 95 "food residual" (i.e. food waste) composting facilities in the U.S. In addition, there are another 9 pilot food residual compost projects, and 14 compost projects are in development. Seven of the compost facilities are located in Vermont.

Food Residual Compost Projects in Vt.

Project	Location
Don Wilson	Arlington
Intervale Compost Proj.	Burlington
Delarichilliere Farms	E. Hardwick
Woodstock Recycling & Refuse	Hartland
Rankin Farms/ Lamoille NRCD	Johnson
Maple Sugar Farm/ Rutland Co. SWD	Wallingsford
Vermont Compost Co.	Montpelier
Source: BioCycle 8/99	

In Vermont, there is significant interest and effort to divert food waste from disposal in landfills. According to the **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revision** published by the Agency of Natural Resources, Waste Management Division (ANR WMD) since 1989 one large and seven on-farm composting facilities that accept food waste began operation. The largest is the Intervale Compost Project (ICP) located in Burlington, which accepted over 1,300 tons of food waste and food processing residuals, and over 9,200 cubic yards of yard trimmings and other organic materials. The ICP is a unique partnership between the non-profit Intervale Foundation and the Chittenden Solid Waste District (CSWD). Starting in January 2000, the Chittenden Solid Waste District is planning on starting a pilot project to collect food waste and other organic residuals from residences in portions of three towns. Other solid waste districts have invested in food waste composting. The Addison County Solid Waste Management District operates a collection vehicle that collects food waste in the county and transports the material either to Foster's Brothers Farm or the Middlebury College compost facility. The Lamoille Regional Solid Waste Management District has developed a program where a private hauler collects food waste from grocery stores, Johnson State College, and restaurants and delivers the material to either the ICP or three on-farm compost facilities. As of October 1999, it appeared this program might stop due to economic factors. According to the Rutland County Solid Waste District's website, the District is investigating food waste composting for future development. In addition to Middlebury College, Saint Michaels College and the University of Vermont have or had active food waste compost programs. A private company, Vermont Compost located in Charlotte operates a mobile composting machine and may accept or compost food waste. The Resource Optimization Technologies (ROT) facility located in Hanover, New Hampshire may accept food waste generated in Vermont. The ROT facility is a two bay in-vessel compost system, one bays is dedicated to food waste and the other is for biosolids.

FOOD WASTE GENERATION

Information on solid waste and food waste generation is not presented in **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revision**, and according to staff of the ANR WMD, the Division does not maintain information specific types of solid waste like food waste.

In order to estimate food waste generation, data on MSW generation in Vermont and the composition of MSW in the U.S. is used. Data on municipal solid waste generation can be derived from the national per capita MSW generation rate presented in **Characterization of Municipal Solid Waste in the United States; 1997 Update**. Based on 1996 MSW generation in the U.S., the national per capita MSW generation rate is 4.3 pounds/day, or 0.78 tons/capita/year. This rate is can be assumed to be representative of Vermont. The U.S. Bureau of the Census estimated Vermont population was 588,978 on July 1, 1997. Applying the Vermont population data to the per capita MSW generation rate, the calculated MSW generation in Vermont was about 462,000 tons in 1997.

Data on MSW composition can also be found in **Characterization of Municipal Solid Waste in the United States; 1997 Update**. According to the **1997 Update**, food waste comprised 10.4% of the MSW generated in the U.S. It is important to note that national MSW composition may not accurately predict a particular state's MSW composition. However, in the **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revision**, the ANR WMD presents MSW composition data from the **1997 Update**, and compared the composition data to Vermont-specific composition data compiled as part of the original **1989 State of Vermont Solid Waste Management Plan**. It is interesting to note that in terms of food waste and yard waste, the 1989 Vermont data compared very closely to the 1996 national data (within 2.8%). This indicates that it is reasonable to use the food waste composition data from the **1997 Update** to estimate food waste generation in Vermont.

Applying the 10.4% food waste percentage to the estimated amount of MSW generated, the calculated amount of food waste generation in Vermont in 1997 is about 48,000 tons.

ESTIMATES OF FOOD WASTE POTENTIALLY AVAILABLE

It is difficult to accurately estimate the amount of food waste that could be potentially available to farm-based anaerobic digestion systems. This is because it is difficult to estimate how much food waste generated in Vermont can be effectively separated and collected from residential, commercial, industrial, and institutional sources. As noted above, the CSWD is about to begin a pilot project where residences will source-separate their food waste (and other organic materials) and place them in a special "organics bin" for composting. The organics bin will be similar to the bins currently used to collect traditional recyclables. The CSWD pilot program should provide good solid information on the ability to source separate residential food waste in urban settings. However, the data is not yet available and may not be applicable to the rural areas of Vermont. Reliable information on the availability of food waste from grocery stores, restaurants, and cafeterias, and other commercial, industrial, or institutional sources is also not available.

The **BioCycle** article notes that food waste composting project typically charge a tipping to accept food waste, and the typical tipping fee at public facilities is between $25 and $35/ton, and the typical fee at private projects is between $20 and $30/ton. Assuming farm-based anaerobic digestion projects charge lower tipping fees than compost facilities, it is likely that at least some food waste collected by solid waste districts, private haulers, or other MSW entities would be delivered to farm-based systems for anaerobic digestion.

Overall, an "educated guess" is 25% to 50% of the food waste generated in Vermont could potentially be available to farm-based anaerobic digestion systems. The guess incorporates several factors affecting food waste availability, which include:

- Not all food waste generated will be separated and/or collected due to lack of interest, costs, contamination, spoilage, odors, storage issues, etc.;
- Compost, animal feed, and other existing options to reuse or recycle food waste will compete with farm-based anaerobic systems for food waste; and
- Transportation distances and costs from areas where food waste is generated and collected to farms with anaerobic digestions systems may be prohibitive.

ENERGY PRODUCTION FROM FOOD WASTE

Food waste encompasses many different materials and the characteristics of food waste vary significantly. A literature search was conducted to locate information on the volatile solids or other characteristics of food waste needed to estimate energy production based on the methodology presented in the Introduction. No or very limited information appears to be available on food waste.

A different approach was needed, and a literature search was conducted on research or data on anaerobic digestion of food waste projects or facilities. This search identified one project in Korea where a pilot-scale two-stage anaerobic digestion plant is used to treat source-separated food waste. Published performance data on the pilot plant indicated that 3 metric tonnes of food waste would produce about 230 m^3 of biogas (at 70% methane), or 1.23 standard cubic feet per pound (SCF/lb). The methane yield from the pilot anaerobic digester appears low compared to a theoretical yield of 8 - 11 SCF/lb volatile solids removed. However it is not possible to compare the two rates because the volatile solids content, moisture content, and other characteristics of the food waste fed into the digester are not known. For purposes of this study, a biogas yield of 1.25 SCF/lb food waste is assumed. Since the biogas contains 70% methane, this indicates the methane yield is about 70% of the biogas yield, or 0.875 SCF CH_4/lb.

Assuming that 25% of the food waste generated in Vermont is potentially available to farm-based anaerobic digestion systems, and the methane yield is 0.785 SCF/lb, the calculated methane production is 30 million SCF per year. Assuming the methane produced has an energy value of 912 Btu/SCF and the electricity conversion equipment has a heat rate of 10,000 Btu/kW-hr, the energy potential of food waste is calculated to be about 220 kW.

BIOSOLIDS

"Biosolids" refers to solids generated by the biological treatment of wastewater at municipal wastewater treatment facilities (WWTFs). Originally termed "sewage sludge" or simply "sludge", the term biosolids was adopted some 5 years ago to help provide a more positive image of the material as well as beneficial use options for the material. The U.S. Environmental Protection Agency (U.S. EPA) as established national regulations and standards for the beneficial use and disposal of biosolids. The regulations and standards are codified in **40 CFR, SUBCHAPTER O, Part 503 - Standards for the Use and Disposal of Sewage Sludge**. Under **40 CFR Part 503**, sewage sludge (i.e. biosolids) are defined as the:

> *"solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage, scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge."*

According to the **State of Vermont 1996 Water Quality Assessment 305(b) Report** published by the Agency of Natural Resources Water Quality Division in December, 1996, 89 municipal WWTFs with National Pollution Discharge Elimination System (NPDES) permits have been constructed in the state. Not included in this number are private WWTFs (such as those at ski areas), industrial WWTFs (that treat domestic wastewater as well as industrial wastewater), or facilities that do not discharge to surface waters. The Agency of Natural Resources Department Waste Management Division (ANR WMD) reports in the **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revision** that 53% of Vermont's population is served by municipal WWTF.

In Vermont, biosolids are either disposed in landfills or by incinerated, or are beneficially used by land application, composting, or as landfill cover (earthen or other materials used to comer solid wastes disposed in landfills to control fires, disease vectors, and odors, to prevent blowing litter, to discourage scavenging by animals, and to provide an aesthetic appearance.). Under **40 CFR Part 503**, sewage sludge must meet specified standards regarding pathogens, vector attraction, and various metal pollutants prior to disposal or beneficial use. Anaerobic digestion is one process that may be used to meet pathogen and vector attraction standards, and many of the larger WWTFs in the state that utilize the activated sludge process for wastewater treatment have anaerobic digestion facilities for sludge treatment. The traditional goal of biosolids anaerobic digestion at WWTF has been volatile solids destruction, pathogen reduction, odor reduction, as well as solids concentration.

A large issue with the use of biosolids in farm-based anaerobic digestion systems is the regulatory oversight that would accompany accepting biosolids. If farm-based anaerobic digestions systems were to accept biosolids, the farms would be viewed as being a beneficial use of biosolids, and would be subject to all federal and state biosolids regulations.

Another consideration is that a significant amount, if not the majority of biosolids are produced by the larger WWTFs in the state, which already utilize anaerobic digestion. The volatile solids content of these biosolids would already be significantly reduced, meaning methane production would be similarly limited.

BIOSOLIDS GENERATION

As part of the **Draft State of Vermont Solid Waste Management Plan; 1999 Plan Revision**, the ANR WMD estimated the quantity of biosolids generated in the state, based on 1997 quantities. The ANR WMD biosolids estimates are presented in Table 5.

TABLE 5: 1997 Vermont Biosolids Generation

Biosolids Management	**In-State** (dry tons)	**Out-of-State** (dry tons)	**Total** (dry tons)	**Percent**
Beneficial Use				
Land Application	1,535	305	1,840	27%
Composting	767	8	775	11%
Landfill Cover	0	94	94	1%
Subtotal	**2,302**	**407**	**2,709**	**40%**
Disposal				
Landfill	3,692	55	3,747	55%
Incineration	0	371	371	5%
Subtotal	**3,692**	**426**	**4,118**	**60%**
TOTAL	**5,994**	**833**	**6,827**	**100%**
Percent	**88%**	**12%**		

As shown in Table 5, 40% of the biosolids generated in Vermont was beneficially used (based on those used defined as beneficial use by the ANR WMD) while the remaining 60% was disposed (by landfilling or incineration) in 1997. According to the ANR WMD, this trend was reversed in 1998 due to a change in how the Chittenden Regional Solid Waste District managed biosolids under its control. Starting in 1998, these biosolids were transported to and composted in Canada. The ANR WMD estimates that in 1998, 60% of biosolids were beneficially used while 40% were disposed.

ESTIMATE OF BIOSOLIDS POTENTIALLY AVAILABLE

The Farm Methane Project Advisory Committee met on August 17, 1999. At this meeting, the ANR WMD data on biosolids generation and management was presented, and biosolids as a potential feedstock for farm-based anaerobic digestion was discussed. As noted in the Meeting Summary, the Committee agreed “that the value of municipal biosolids may not be as an organic resource to be combined with dairy manure.” The key factors that affected the Committee’s decision were:

- If farm were to accept biosolids for anaerobic digestion, the digesters and management of the digested solids and liquids would be subject to federal and state biosolids regulations;
- Much of the municipal biosolids generated are anaerobically digested, and thus have reduced volatile solids content indicating this material will have limited potential to produce methane and energy, and
- The use of biosolids in agricultural and residential applications is controversial, and farms that accept biosolids for anaerobic digestion my face limited options regarding the ultimate disposal or used of digested biosolids.

Due to the Committees decision, no biosolids are assumed to be potentially available for farm-based anaerobic digestion.

ENERGY PRODUCTION FROM BIOSOLIDS CURRENTLY DISPOSED

As noted above, no biosolids are assumed to be potentially available due to regulatory, volatile solids content, and perception factors.

CONCLUSIONS

The resource identified and quantified dairy manure and other organic residues and wastes, in addition to dairy manure, that could be used in farm-based anaerobic digestion systems, including

- Other manures (hogs and pigs, horses and ponies, poultry, goats, and sheep and lambs);
- Cheese whey;
- Food processing residuals;
- Brewery residuals; and
- Food waste

Although biosolids were considered, they were ultimately rejected due to concerns over regulations, volatile solids content (which affects biogas production), and public perception.

A summary of the organic residues and wastes generated, potentially available, and electrical energy potential is presented in Table 6. Overall, over 5.1 million wet tons per year of organic residues and waste are generated in Vermont. Of this amount, over 3.4 million wet tons per year, or about 2/3 of that generated is potentially available for farm-based anaerobic digestion. The amounts generated and potentially available are reported as minimums since some materials are quantified in other units than wet tons. The estimated electricity generation potential of methane produced by farm-based anaerobic digestion of the materials is just under 30,000 kW (or 30 MW). Assuming there are 1,693 active dairy farms in the state (based on Department of Agriculture, Food and Markets inspection reports for July 1999), the overall average generation potential per dairy farm is calculated to be just under 18 kW.

The overall average generation potential appears to exceed the average electricity use on Vermont farms. Presented in Figure 1 is the average daily electricity use on farms in the Central Vermont Power Service (CVPS) service territory. Figure 1 is based on the average hourly electricity use for about 780 farms. As shown in Figure 1, the average electricity use on farms in the CVPS service territory peaks at about 7 am and 6 pm with peak electricity use at just under 15 kW. It appears reasonable to assume that electricity use on farms is the CVPS service territory is similar to that used on farms statewide.

It is important to note that although the potential to generate electricity (through anaerobic digestion) appears to exceed electricity use on Vermont farms, this does not necessarily imply that anaerobic digestion systems make sense for Vermont farms. This is because many factors affect the technical, environmental and/or regulatory, and economic feasibility of farm-based anaerobic digestion systems, in addition to electricity generation potential and electricity use. In order to determine the feasibility of installing and operating farm-based anaerobic digestion systems, analysis of specific farms should be completed that take into account the technical, environmental and/or regulatory, economic, and other factors affecting each farm.

The results indicate that from an energy potential standpoint, dairy manure represents the vast majority of the resource available in Vermont. About 94% of the estimated 30,000 kW potential is from dairy manure. Cheese whey, at about 3% of the total resource, is the next largest resource, followed by other manures (2% of the total resource) and food waste (1% of the total resource). Brewery residuals and food processing residuals are best described as having minimal energy potential.

The results of the resource assessment strongly suggest the Vermont Department of Public Service (DPS) and the Vermont Department of Agriculture, Food and Markets (AGR) project focus primarily on dairy manure as the "feedstock" for farm-based anaerobic digestion systems. The results suggest that overall, the other organic residuals and wastes will have at best a minor impact on energy production in farm-based systems. However, this should in no way discount the role the other residuals and wastes could play in individual systems. These systems could help the state, solid waste districts, and industry achieve solid waste management and recycling goals for organic residuals and wastes. The research conducted as part of this study indicate that an appropriately located farm-based anaerobic digestion system could receive significant quantities of the other residues and wastes. Staff at two companies, one that generates brewery wastewater and one that generates food processing residuals indicated that if farm-based systems were available now, they would seriously consider using them. The total or overall cost (including transportation, processing, and tipping fee, if charged) is a key factor ultimately affecting their decision to use or not use farm-based systems. But it appears that if farms charged low or no tipping fees to accept the material, the companies would transport their residuals to the farm. At least three solid waste districts (Chittenden, Lamoille, and Rutland) are seriously considering implementing or expanding food waste collection and beneficial use programs. Again, cost will be a driving factor, but if farms accept the material for a low tipping fee, it is reasonable to assume that the districts will utilize farm-bases systems.

SUGGESTED NEXT STEPS

As noted in the Introduction, this study is a macro- or statewide resources assessment, which estimates resources generated and potentially available throughout the entire state. While this information is very important to understanding the potential of farm-based anaerobic digestion systems in Vermont, it is of limited use to understanding what organic residuals and wastes would be available to specific farms. The overall anaerobic digestion project (being completed by DPS and AGR) includes feasibility studies of specific farms to understand how and where anaerobic digestion systems would benefit Vermont farms. One task that could assist with the feasibility studies is micro- or farm-specific resource assessments. The farm-specific resource assessments would identify specific organic residuals and wastes available for anaerobic digestion, and would also provide information on the delivered cost of the residues and wastes. The availability and cost of residuals and wastes will likely have a significant impact on the economic feasibility of farm-based anaerobic digestion systems.

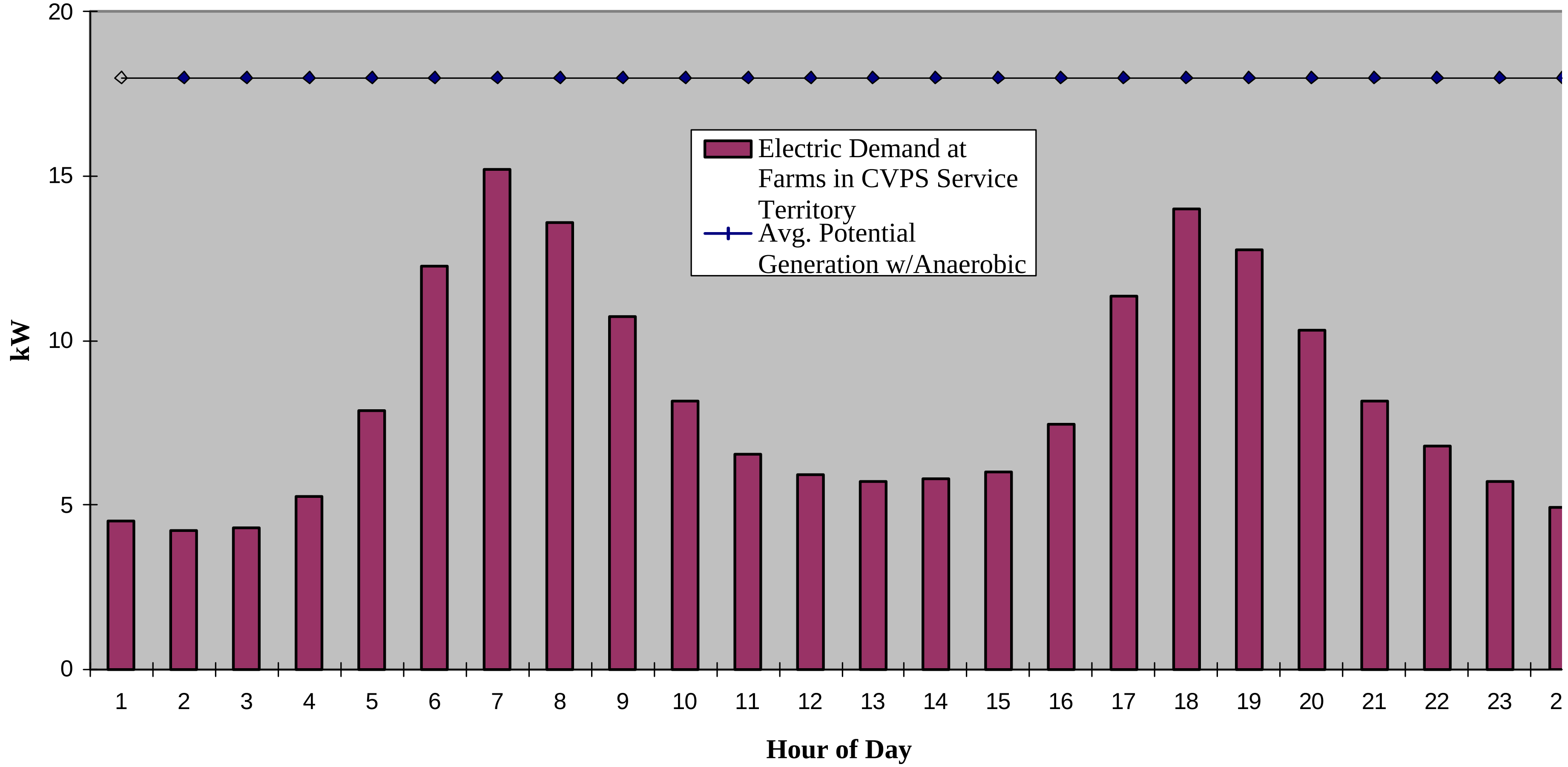
As noted above, the statewide average electricity generation potential is about 18kW per farm, which appears to be relatively small. To illustrate this point, consider Vermont's net metering law, which allows "farm systems" (i.e. one which "generates electric energy from the anaerobic digestion of agricultural waste produced by farming, and which is located on the farm where substantially all of the waste used is produced.") to generated up to 100 kW. The average per farm generation potential suggests cooperative or community anaerobic digestion systems may be more feasible than individual farm systems. Another task could be to identify locations in the state with high dairy cow or other livestock population densities (i.e. animal units per unit area), and to investigate the feasibility of cooperative- or community-based systems. As part of these studies, a micro- or region-specific resource assessment could be completed to identify the types and amount of organic residues and waste potentially available the cooperative- or community-based system.

TABLE 6: Summary of Organic Residuals and Wastes Potentially Available in Vermont

ORGANIC RESIDUE OR WASTE	AMOUNT GENERATED (tons/year)[(a)]	POTENTIALLY AVAILABLE (tons/year)[(a)]	CHARACTERISTICS[(b)]	ENERGY POTENTIAL ($kW_{electric}$)
DAIRY MANURE	4,053,600	3,121,300	12.5% Solids VS=85% of TS	**28,000 kW**
OTHER MANURES				
Beef Cows	276,000	27,600	11.6% Solids VS=85% of TS	230 kW
Hogs and Pigs	6,000	3,000	10.0% Solids VS=87% of TS	20 kW
Horses and Ponies	241,000	24,100	22% Solids VS=85% of VS	380 kW
Poultry	8,000	5,400	25% Solids VS=78.5% of TS	90 kW
Goats	3,000	300	25% Solids VS=83% of TS	10 kW
Sheep and Lambs	18,000	1,800	25% Solids VS=83% of TS	30 kW
				Subtotal = 760 kW
CHEESE WHEY	459,000	184,000	6-7% Solids VS=92% of TS	**990 kW**
FOOD PROCESSING RESIDUALS				
Wastewater	310,000 gal/yr	310,000 gal/yr	10,000 mg/l BOD	1.5
Lagoon Sludge	100,000 to 400,000 gal/yr	100,000 to 400,000 gal/yr	15,000 mg/l VS	0.5 to 2.1
Production Line Rejects	120 to 180	120 to 180	20% Solids VS=85% of TS	1.7 to 2.5
				Subtotal = 3.7 to 6.1 kW
BREWERY RESIDUALS				
Spent Grains	2,000	0		0
Spent Yeast	133	0		0
Wastewater	9,300,000 to 18,600,000 gal/year	1,300,000 gal/yr	7,000 mg/l BOD COD/BOD =1.67 $COD_{removal}$ = 75%	5
				Subtotal = 5 kW
FOOD WASTE	48,000	12,000	0.875 SCF CH_4/lb	**220 kW**
			TOTAL	**29,760 kW**
Available, but deemed not appropriate for farm-based anaerobic digestion				
BIOSOLIDS	5,994 dry tons/yr	0[(c)]	VS=70% of TS	**0 kW**

(a): All units are wet tons, except where noted.
(b): TS: Total solids
VS: Volatile solids
BOD: Biological oxygen demand
COD: Chemical oxygen demand
$COD_{removed}$: Chemical oxygen demand removed during anaerobic digestion
SCF: Standard cubic feet
CH4: Methane

FIGURE 1: Average Electric Demand at Farms and Average Generation Potential



Appendix A:

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